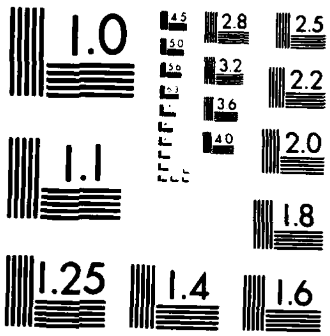
AD-A150 600 THE ORIENTATION DISTRIBUTION OF NONSPHERICAL AEROSOL PARTICLES WITHIN A C..(U) HEBREW UNIV JERUSALEM (ISRAEL) DEPT OF ATMOSPHERIC SCIENCES I GALLILY NOV 84 1/1

UNCLASSIFIED CRDC-CR-84118 DAJA45-83-C-004 F/G 20/4 NL

END

FILMED

DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

(2)

CRDC-CR-84118

THE ORIENTATION DISTRIBUTION OF NONSPHERICAL AEROSOL PARTICLES WITHIN A CLOUD

INTERIM REPORT

by Isaiah Gallily

DEPARTMENT OF ATMOSPHERIC SCIENCES
The Hebrew University of Jerusalem
Jerusalem, Israel

November 1984

US Army Armament, Munitions & Chemical Command
Aberdeen Proving Ground, Maryland 21010-5423

Disclaimer

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorizing documents.

Disposition

For classified documents, follow the procedures in DOD 5200.1-R, Chapter IX or DOD 5220.22-M, "Industrial Security Manual," paragraph 19. For unclassified documents, destroy by any method which precludes reconstruction of the document.

Distribution Statement

Approved for public release; distribution unlimited.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) CRDC-CR-84118	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Department of Atmospheric Sciences The Hebrew University of Jerusalem 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION USARDSG-UK
6c. ADDRESS (City, State, and ZIP Code) Jerusalem, Israel	7b. ADDRESS (City, State, and ZIP Code) Box 65 FPO NY 09510
8a. NAME OF FUNDING/SPONSORING ORGANIZATION US Army Chemical Research and Development Center 8b. OFFICE SYMBOL (If applicable) SMCCR-RSP-B	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER DAJA45-83-C-004
8c. ADDRESS (City, State, and ZIP Code) Aberdeen Proving Ground, MD 21010-5423	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO.: — PROJECT NO.: 1L162662 TASK NO.: A552 WORK UNIT ACCESSION NO.: —

11. TITLE (Include Security Classification)

The Orientation Distribution of Nonspherical Aerosol Particles Within A Cloud - Interim Report

12. PERSONAL AUTHOR(S)

Gallily, Isaiah

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Contract	FROM 83 Dec TO 84 Mar	1984 November	18

16. SUPPLEMENTARY NOTATION

COR: Glenn O. Rubel, SMCCR-RSP-B (301) 671-2760

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)	
FIELD	GROUP	SUB-GROUP		
15	02		Aerosols	Distribution
			Nonspherical aerosols	Fibrous aerosols
			Orientation	Platelet aerosols

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The orientation distribution function of fibrous and platelet-like aerosol particles was calculated for a general laminar flow by solving the Fokker-Plank equation. It has been found that this function shows maxima and minima, which indicates a preferred orientation. The cases of a point source and a laminar jet are brought out as an example.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL BRENDA C. ECKSTEIN	22b. TELEPHONE (Include Area Code) (301) 671-2914 22c. OFFICE SYMBOL SMCCR-SPS-IR

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

PREFACE

The work described in this report was authorized under Contract No. DAJA45-83-C-004. This work was started in December 1983 and completed in March 1984.

The use of trade names in this report does not constitute an official endorsement or approval of the use of such commercial hardware or software. This report may not be cited for purposes of advertisement.

Acknowledgments

The author expresses his appreciation to co-investigator E. M. Krushkal.

Blank

CONTENTS

Blank

THE ORIENTATION DISTRIBUTION OF NONSPHERICAL
AEROSOL PARTICLES WITHIN A CLOUD

1. GENERAL

The orientation distribuiton function F of nonspherical aerosol particles is very decisive for many cloud properties such as light scattering and radiative transfer (1,2), diffusional transport mechanics (3-5) and average rate of sedimentation (6).

It is also very important in rheology for the constitutive properties of non-Newtonian fluids (7-9).

In general, the orientation function is affected by two opposing physical factors: The randomizing action of the rotational Brownian motion (or micro-turbulent eddies) and the orienting influence of flow gradient.

Up to now, the studied situations were those of the (asymptotic) weak and strong field in which the rotational Peclėt number α which indicates the ratio between the above factors, viz. $\alpha = W^{\circ} / D^{*}$ was

$\alpha \ll 1$ or $\alpha \gg 1$. Likewise,

the investigations were rather concerned with the simple shear flows.

2. AIM OF STUDY

Since many cases of significance are characterized by values of α of the order of unity, as occurs in the free atmosphere and with typically-sized particles, it became of interest to study these cases. In addition, the general laminar field where the nine components of the gradient tensor had to be treated once for its own significance and second time for employing it in models for the real, <u>turbulent</u> atmosphere.

3. BASIC EQUATIONS AND ASSUMPTIONS

The basic equation in the reported study was the (source-free) Fokker-Planck equation of conservation in angle-space

$$\partial F / \partial t + \nabla \cdot (F \boldsymbol{\omega} - \mathbf{D} \cdot \nabla F) = 0 \quad . \tag{1}$$

*For nomenclature see Appendix

We have considered a system of small spheroidal particles immersed in a general laminar flow which is given in their vicinity by the linear relationship.

$$\mathbf{u}(\mathbf{x},t) = \mathbf{W}(t) \cdot \mathbf{x} \quad . \tag{2}$$

The small particles simulate (asymptotically) straight long fibers or flat platelets which are used in many applications.
The rotational velocity of the particles $\boldsymbol{\omega}$ of Eq.[1] was taken to be given by the Jeffery's equation (10)

$$\omega_i = \frac{1}{2}\left[V'_{kj} + S'_{kj}\,(a_j^2 - a_k^2)/(a_j^2 + a_k^2)\right] \tag{3}$$

where i, j, $k \rightarrow 1,2,3$ are cyclic permutation indices, a_i, a_j, a_k are the semi-axes of the ellipsoids, $V'_{ij} = W'_{ij} - W'_{ji}$; $S'_{ij} = W'_{ij} + W'_{ji}$; $W'_{ij} = \partial u'_i / \partial x'_j$ and $\mathbf{u}'(\mathbf{x},t)$, $\mathbf{x}$ are respectively the (fluid) velocities and location vector in the body-locked coordinate system $\mathbf{x}'$ (Fig.1)

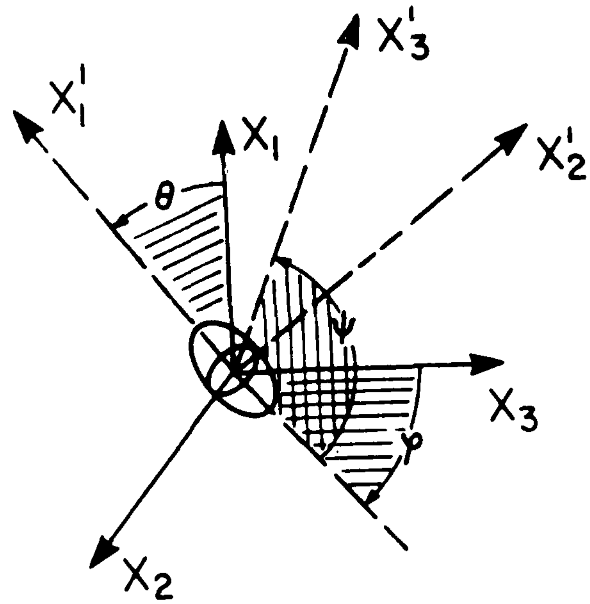


Fig. 1. The two coordinate systems, $\mathbf{x}'$ (body locked) and $\mathbf{x}$ (external) used in the analysis; φ, θ, ψ -Eulers' angles

Here, using the usual kinematic relationships between θ, φ ($\psi = 0$) and ω_1', ω_2', ω', and the similarity transformation between the x' and x systems, we finally obtained that

$$\dot{\varphi} = V/2 + ctg\,(E_{31}\,c\varphi - E_{21}\,s\varphi) - \lambda\,(S_{32}\,c_2\varphi - Q_1\,s_2\varphi)$$

and

$$\dot{\theta} = G_{2131}\,c^2\theta - G_{1213}\,s^2\theta + \frac{\lambda}{2}\,s_2\theta\,(Q_2 + Q_1\,c_2\varphi + S_{32}\,s_2\varphi) \tag{4}$$

in which $E_{ik} = \frac{1}{2}(V_{ik} + \lambda S_{ik})$, $G_{ijk\ell} = E_{ij}\,c\varphi + E_{k\ell}\,s\varphi$,

$Q_1 = \frac{1}{2}(W_{22} - W_{33})$, $Q_2 = \frac{1}{2}(W_{22} + W_{33} - 2W_{11})$, $V_{ik} = W_{ik} - W_{ki}$,

$S_{ik} = W_{ik} - W_{ki}$, $W_{ik} = \partial u_i / \partial x_k$, $c_m\varphi = \cos m\varphi$, $c^m\varphi = \cos^m\varphi$,

$s_m\varphi = \sin m\varphi$, $s^m\varphi = \sin^m\varphi$ etc., $\lambda = (R^2 - 1)/(R^2 + 1)$, $R = a_1/a_2$.

Now, after non-dimensionalization by designating $\tilde{W}_{ik} = W_{ik}/W_o$ and $\tilde{t} = t\,W_o$ (W_o - a typical gradient component), we could convert the Fokker-Planck equation to the form*

*The $\sim$ sign is dropped out for the sake of simplicity.

$$\partial F/\partial t + \frac{1}{\sin\theta}\frac{\partial}{\partial\theta}(F\dot{\theta}\sin\theta) + \frac{\partial}{\partial\varphi}(F\dot{\varphi}) = \Delta F/\alpha \tag{5}$$

where D is the mid-diameter rotational diffusion coefficient of the axially symmetric particles. The normalization condition was taken, as ususal, to be

$$\int_0^{2\pi}\int_0^{\pi} F \sin\theta \, d\theta \, d\varphi = 1 \quad . \tag{6}$$

4. SOLUTION OF THE FOKKER-PLANCK EQUATION

According to the theory of Fourier series, we wrote down the solution to Eq. [5] as a series of spherical harmonics

$$F = \sum_{n=0}^{\infty} \sum_{m=0}^{n} (1 - \tfrac{1}{2}\delta_{m0}) \left[A_{0n}^{m}(t)\, c\ \varphi + A_{1n}^{m}(t)\, s\ \varphi\right] \; P_n^m(c\theta) \quad . \tag{7}$$

Thus, inserting [7] into [5] and taking account of the symmetry properties of the physical problem, we obtained for the A-coefficients the set of the simultaneous equations

$$\frac{dA_{kn}^{m}}{dt} = -\frac{n(n+1)}{\alpha} A_{kn}^{m} - \sum_{j=n-2}^{n+2} \sum_{p=m-2}^{m+2} \sum_{\ell=1}^{2} (1 + \delta_{m0})$$

$$\times \left[D_{\ell,jn}^{pm} \; A_{kj}^{m} + (-1)^k C_{\ell,jn}^{pm} \, A_{1-k,j}^{p} \right] \tag{8}$$

in which $D_{\ell,jn}^{pm}$, $C_{\ell,jn}^{pm}$ are functions of S_{ik} , V_{ik} , Q_1, Q_2 and the size parameter λ defined above.*

The latter were numerically solved by the employment of a fast differential equations-solver based on an extrapolation method of Burlish and Stoer.(11) It turned out that our general solution included previous work as special cases.

*See Proceedings of the 1983 CSL Scientific Conference, Aberdeen Proving Ground, MD (to be published).

5. NUMERICAL RESULTS

Considering realistic situations of particles with a characteristic size of $r \sim 10^{-5} - 10^{-3}$ cm. (whose computed D is $D \sim 1 \ \mathrm{sec}^{-1}$), typical flow velocities and gradients of 1-10 m.sec^{-1} and 1-10 sec^{-1}, respectively, we came out with Peclét number values of $\alpha \sim$ 1-10.

As indicative examples, we bring out here the cases of:

i. A point source flow whose velocity is given by

$$\mathbf{u} = q_0 \, \mathbf{r} / 4\pi r^3 \tag{9}$$

and whose gradient is

$$W = \frac{\delta_{ik}}{r^3} - \frac{3 x_i x_j}{r^5} \tag{10}$$

where x_i is normalized by a typical length r_0, $\mathbf{r}(x_i)$ is the radius vector, $W_0 = q_0/4\pi r_0^3$ and q_0 a constant.

ii. A round laminar jet whose axial (u_1) and radial (u_r) velocity components are (12)

$$u_1 = \frac{2\gamma^2 \nu}{x_1} f(\xi) \tag{11}$$

and

$$u_r = \frac{\gamma \nu \xi}{x_1} (1 - \xi^2/4) f(\xi) \tag{12}$$

and the gradient components are

$$W_{11} = -\eta(1 - 3\xi^2/4), \quad W_{1r} = -\gamma\eta\xi, \quad W_r = W_{11}\xi/\gamma,$$

$$W_{rr} = \frac{1}{2}\eta\left(1 - \frac{3}{2}\xi^2 + \frac{\xi^4}{16}\right) + \frac{u_r}{r} \tag{13}$$

where $\xi = \gamma r/x_1$, $f(\xi) = (1 + \xi^2/4)^{-2}$, γ is determined by the jets' momentum J, $J = (16/3)\pi\rho\gamma^{-2}\nu^2$, r is the radial distance (again) and r, x_i are later on non-dimensionalized by r_0.

Indicative results for these two significant flows are presented in Figs. 2,3 and 4,5 in which a preferred orientation of the considered particles is clearly seen by the pronounced maxima of F.

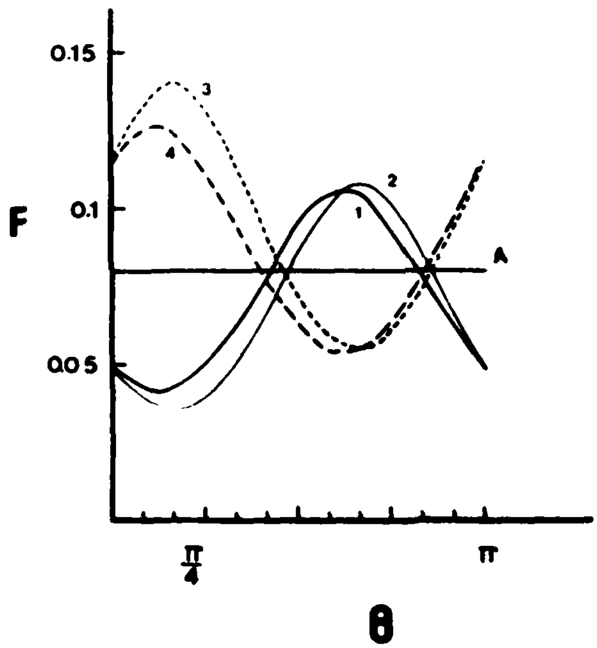


Fig. 2. The orientation distribution function F vs the (Euler) angle θ in a point source flow $\alpha = 1$, $R = 0.02$ (platelets) and R = 50 (straight fibers).

$\tilde{t}\ (= t\,W_0) \geqq 2$, $x_1 = 1$, $x_2 = x_3 = 0.4$; $A - t = 0$ (random orientation);

——, $R = 50$: $1 - \psi = 0$, $2 - \psi = \pi/4$; — —, $R = 0.02$: $3 - \psi = 0$, $4 - \psi = \pi/4$.

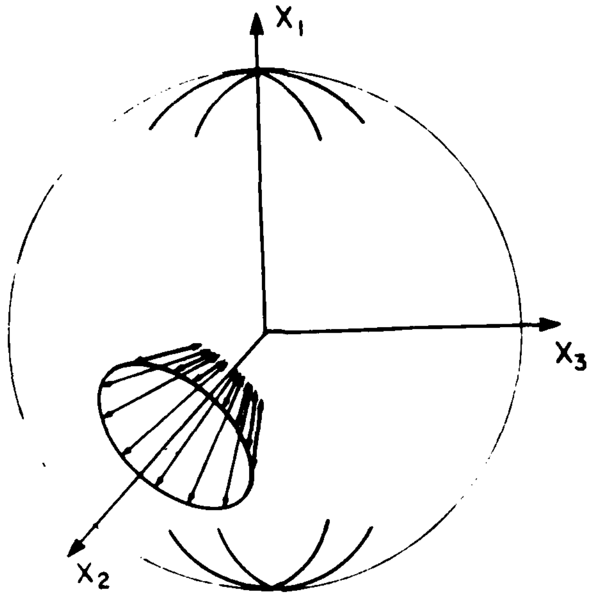


Fig 3. A perspective view of particle orientation in a point source field (schematical)

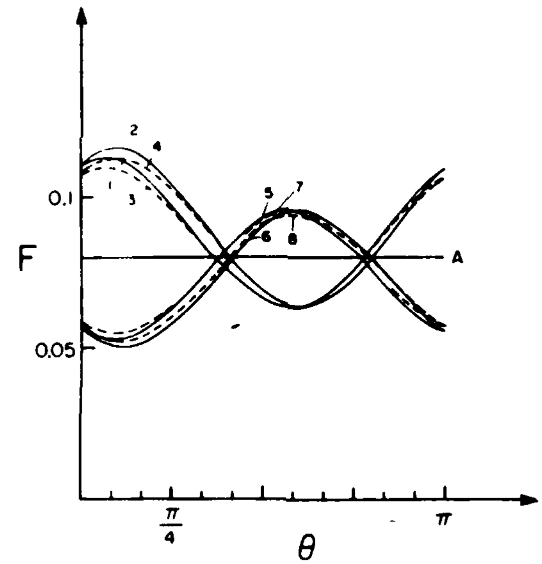


Fig. 4. The orientation distribution function F vs the(Euler) angle θ in a flow of a laminar, axi-symmetric jet $\alpha = 1$, $R = 0.01, 0.2, 5, 100$.

$\tilde{t} = (t W_0) \geq 2$, $x_1 = 1$, $x_2 = x_3$, $\xi = 0.5$, $\gamma = 1$, $\varphi = 0, \pi/4$.

1 - $R = 0.01$, $\varphi = 0$; 2 - $R = 0.01$, $\varphi = \pi/4$; 3 - $R = 0.2$, $\varphi = 0$;

4 - $R = 0.2$, $\varphi = \pi/4$; 5 - $R = 5$, $\varphi = 0$; 6 - $R = 5$, $\varphi = \pi/4$;

7 - $R = 100$, $\varphi = 0$; 8 - $R = 100$, $\varphi = \pi/4$.

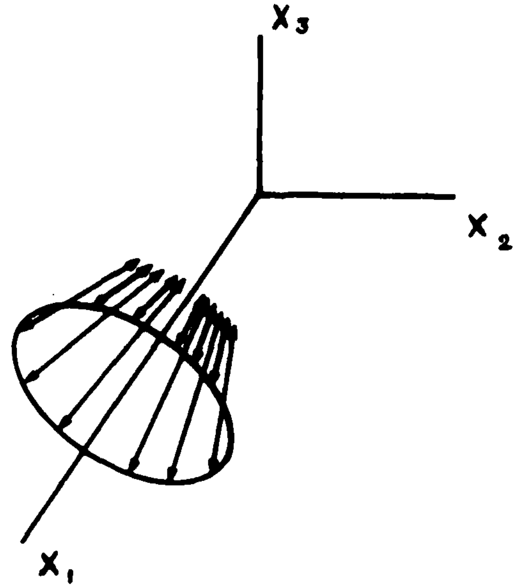


Fig. 5. A perspective view of particle orientation in a laminar jet (schematical)

6. SUMMARY

The orientation distribution function of fibrous and platelet-like aerosol particles was calculated for a general laminar flow by solving the Fokker-Planck equation.

It has been found that this function shows maxima and minima, which indicates a preferred orientation. The cases of a point source and a laminar jet are brought out as an example.

7. FUTURE PLANS

Based on the reported study, the next stage of research on the orientation within a turbulent cloud is now in progress.

LITERATURE CITED

1. Heller, W., Wada, E., and Papazian, L. A. J. Polymer Sci. 41, 481 (1961).

2. Okano, K., and Wada, E. J. Chem. Phys. 34, 405 (1961).

3. Eisner, A. D., and Gallily, I. J. Colloid Interface Sci. 81, 214 (1981).

4. Eisner, A. D., and Gallily, I. Ibid. 88, 185 (1982).

5. Eisner, A. D., and Gallily, I. Ibid. (1984) in press.

6. Happel, J., and Brenner, H. Low Reynolds Number Hydrodynamics. pp 5-8 Prentice-Hall, NJ. 1965.

7. Peterlin, A. Z. Phys. 111, 232 (1938).

8. Hinch, E. J., and Leal, L. G. J.Fluid Mech. 76, 187(1976); Ibid, 92, 591 (1979).

9. Rallison, J. M. J. Fluid Mech. 84, 231 (1978).

10. Jeffery, G. B. Proc. Roy. Soc. A102, 161 (1923).

11. Burlish, R., and Stoer, J. J. Num. Math. 8, 1 (1966).

12. Schlichting, H. Boundary Layer Theory. p 220. McGraw-Hill, New York. 1968.

Blank

APPENDIX. NOMENCLATURE

a_i , a_j , a_k - half axes of an ellipsoidal particle

A^m_{on} , A^m_{1n} - coefficients in expansion as spherical harmonics

$C^{pm}_{\ell,jn}$ $D^{pm}_{\ell,jn}$ - coefficients in Eq. [8]

$\mathbf{D}$, D - rotational diffusion tensor and coefficient, respectively

E_{ik}, $G_{ijk\ell}$, a_1, a_2 - defined in text

F - orientation distribuiton function

i, j, k, ℓ, m, p - indices

$\mathbf{r}$ -radius vector; r_o - normalizing radius vector

$R = a_1 / a_2$

S'_{ik} , S_{ik} - defined in text

t - time

$\mathbf{u}$ - flow velocity

V'_{ik} , V_{ik} - defined in text

W'_{ik} , W_{ik} - component of the gradient tensor; -normalizing component

$\mathbf{x}'$, $\mathbf{x}$ - location vectors.

Greek Letters

α – rotational Peclet numbers

γ – parameter related to jet's momentum

δ_{ij} – Kroneckers' delta

φ, θ, ψ – Eulers' angles

$\boldsymbol{\omega}$ – rotational velocity of the particle

$\boldsymbol{\nabla}$ – nabla operator in angle-space

Δ – Laplacian operator in angle-space

Blank

DISTRIBUTION LIST 1

Names	Copies
Commander US Army Chemical Research and Development Center	
ATTN: SMCCR-CBA	1
SMCCR-CBB	1
SMCCR-CBC	1
SMCCR-ET	1
SMCCR-MSS	1
SMCCR-MU	1
SMCCR-MUA	1
SMCCR-MUP	1
SMCCR-MUS	1
SMCCR-MUS-A	1
SMCCR-OPF	1
SMCCR-OPP (TTCP)	6
SMCCR-PMI	1
SMCCR-RS	1
SMCCR-RSC	1
SMCCR-RSL	1
SMCCR-RST	1
SMCCR-RST-E	1
SMCCR-SF	1
SMCCR-SPM	1
SMCCR-SPS-IL	2
SMCCR-SPS-IR	2
SMCCR-RSA (Record cy)	1
SMCCR-RSP-B (COR: Glenn Rubel)	5
Aberdeen Proving Ground, MD 21010-5423	
Commandant US Army Ordnance Missile and Munitions Center and School	
ATTN: ATSK-CM	1
ATSK-EI (Mr. Cranford)	1
ATSK-TME	1
Redstone Arsenal, AL 35897-6700	
Commander US Army Missile Command	
ATTN: AMSMI-ROC (Dr. B. Fowler)	1
Redstone Arsenal, AL 35898-5242	
Commander US Army Missile Command Redstone Scientific Information Center	
ATTN: AMSMI-RPR (Documents)	2
Redstone Arsenal, AL 35898-5241	

Names	Copies
Commander US Army Missile Command	
ATTN: AMSMI-RGT (Mr. M. Maddix)	1
AMSMI-RKL (Dr. W. Wharton)	1
AMSMI-YDL, Bldg 4505	1
AMSMI-YLP (Mr. N. C. Kattos)	1
Redstone Arsenal, AL 35898-5500	
Commandant US Army Chemical School	
ATTN: ATZN-CM	1
ATZN-CM-CC	1
ATZN-CM-CS (Deputy MLSO)	1
ATZN-CM-MLB	1
Cbt Dev Smoke (CPT Gray)	1
Fort McClellan, AL 36205-5020	
Commander US Army Electronic Proving Ground	
ATTN: STEEP-MM-IS (FIO Officer)	1
STEEP-MT-DS (CPT Decker)	1
Fort Huachuca, AZ 85613-7110	
Commander Naval Weapons Center	
ATTN: Code 3893 (Dr. C. E. Dinerman)	1
Code 3893 (Dr. L. A. Mathews)	1
Code 3918 (Dr. F. T. Wu)	1
China Lake, CA 93555	
Commander USASTCFEO	
ATTN: Medical/Chemical Officer	1
APO San Francisco 96328-5000	
Commander North American Air Defense Command	
ATTN: J31CN	1
Cheyenne Mountain Complex Peterson AFB, CO 80914-5601	
Director Defense Intelligence Agency	
ATTN: DB-4G1	1
Washington, DC 20301-6111	

Director
Office Environmental and Life Sciences
Office of Under Secretary of Defense (R&E)
ATTN: Mr. Thomas R. Dashiell 1
The Pentagon
Washington, DC 20301-3080

HQDA
ATTN: DAMO-NCC 1
WASH DC 20310-0430

HQ, ODCSOPS
ATTN: DAMO-FDD 1
WASH DC 20310-0460

HQDA
ATTN: DAMA-ARR (Dr. Verderame) 1
WASH DC 20310-0632

HQDA
ATTN: DAMA-CSS-C 1
WASH DC 20310-0643

HQDA (DAEN-RDM/Dr. R. B. Gomez) 1
WASH DC 20314

Commander
Air Force Office of Scientific Research
ATTN: NE (MAJ J. W. Hager) 1
Bolling AFB, DC 20332

Commander
Naval Air Systems Command
ATTN: Code AIR-320R (Dr. H. Rosenwasser) 1
Code AIR-53634F (D. C. Caldwell) 1
Washington, DC 20361

Commander
Naval Research Laboratory
ATTN: Code 5711 (Dr. W. E. Howell) 1
Code 6182 (Dr. R. Taylor) 1
Code 6532 (Mr. Curcio) 1
Code 6532 (Dr. G. Trusty) 1
Code 6530-2 (Mr. G. Stamm) 1
Code 8326 (Dr. J. Fitzgerald) 1
4555 Overlook Avenue, SW
Washington, DC 20375-5000

Commandant
HQ, US Marine Corps
ATTN: Code LMW-50 1
Washington, DC 20380-0001

Federal Emergency Management Agency
Civil Defense Division (Room 625)
ATTN: NP-CP-CD (Mr. David Freund) 1
500 C Street, SW
Washington, DC 20472

Commander
Air Force Armament Laboratory
ATTN: DLJW (Mr. L. Nelson) 1
Eglin AFB, FL 32542-5000

OSU Field Office 1
PO Box 1925
Eglin AFB, FL 32542-1925

Commander
Air Force Systems Command
ATTN: AD/YQ 1
Eglin AFB, FL 32542-5000

Commander
Tactical Air Warfare Center
ATTN: THLO (LTC Kotouch) 1
Eglin AFB, FL 32542-6008

Commander
US Army Infantry Center
ATTN: NBC Branch, Directorate of Plans
and Training (Bldg 2294) 1
Fort Benning, GA 31905-5273

Commandant
US Army Infantry School
ATTN: ATSH-CD-MLS-F (Mr. D. Dowie) 1
Fort Benning, GA 31905-5400

Commandant
US Army Infantry School
ATTN: ATSH-B, NBC Branch 1
Fort Benning, GA 31905-5410

Commander
US Army Armament, Munitions and
Chemical Command
ATTN: AMSMC-ASN 1
AMSMC-IRD-T 1
AMSMC-SFS 1
SMCAR-ESP-L 1
Rock Island, IL 61299-6000

Director
US Army Materiel Command Field
Safety Activity
ATTN: AMXOS-SE (Mr. Yutmeyer) 1
Charlestown, IN 47111-9669

Commander
Naval Weapons Support Center
ATTN: Code 50C (Dr. B. E. Douda) 1
Code 502 (R. Farren) 1
Code 5062 (C. LohKamp) 1
Crane, IN 47522-5050

Commander
US Army Combined Arms Center
Development Activity
ATTN: ATZL-CAM-M 1
Fort Leavenworth, KS 66027-5300

Commander
89th Medical Group (P) 1
3130 George Washington Blvd
Wichita, KS 67210

Commander
US Army Armor Center and Fort Knox
ATTN: ATZK-CD-MS 1
ATZK-DPT-N (NBC School) 1
Fort Knox, KY 40121-5000

Commander
5th Infantry Division (Mech)
ATTN: AFZX-CL 1
Fort Polk, LA 71459

Commander
Hanscom Air Force Base
ATTN: AFGL/POA (Dr. F. Volz) 1
Bedford, MA 01731

Commander
Natick Research and Development Center
ATTN: STRNC-O 1
Natick, MA 01760-5015

Commander
Natick Research and Development Center
ATTN: STRNC-ICC 1
Natick, MA 01760-5019

Commander
US Army Materials and Mechanics
Research Center
ATTN: AMXMR-MDF (Dr. S. Isserow) 1
Watertown, MA 02172-0001

Commander
Naval Intelligence Support Center
ATTN: Code 434 (H. P. St. Aubin) 1
4301 Suitland Road
Suitland, MD 20390

Commander
US Army Intelligence and Security
Command
ATTN: IAFM-SED-III 1
Fort Meade, MD 20755-5000

Commander
US Army Electronics Research
and Development Command
ATTN: AMCCM-EO (Mr. E. Dudley) 1
Adelphi, MD 20783-1145

Commander
Harry Diamond Laboratories
ATTN: DELHD-RDC (Mr. D. Giglio) 1
DELHD-RT-CB (Dr. Sztankay) 1
2800 Powder Mill Road
Adelphi, MD 20783-1197

Director
US Army Concepts Analysis Agency
ATTN: MOCA-SMC (S. Penn) 1
8120 Woodmont Avenue
Bethesda, MD 20814-2797

Project Manager
Smoke/Obscurants
ATTN: AMCPM-SMK-E (A. Van de Wal) 1
AMCPM-SMK-M 1
AMCPM-SMK-S 1
AMCPM-SMK-T 1
Aberdeen Proving Ground, MD 21005-5001

Commander
US Army Test and Evaluation Command
ATTN: AMSTE-CM-F 1
AMSTE-CT-T 1
Aberdeen Proving Ground, MD 21005-5055

Director
US Army Ballistic Research Laboratory
ATTN: AMXBR-SECAD (Dr. A. Gauss, Jr.) 1
AMXBR-SECAD (Mr. A. La Grange) 1
AMXBR-OD-ST (Tech Reports) 1
Aberdeen Proving Ground, MD 21005-5066

Director
US Army Materiel Systems Analysis
Activity
ATTN: AMXSY-J (Mr. J. O'Bryon) 1
AMXSY-GC (Mr. F. Campbell) 1
AMXSY-MP (Mr. H. Cohen) 1
Aberdeen Proving Ground, MD 21005-5071

Commander
US Army Environmental Hygiene Agency
ATTN: HSHB-O/Editorial Office 1
Aberdeen Proving Ground, MD 21010-5422

Commander
US Army Armament, Munitions and
Chemical Command
ATTN: AMSMC-MAR-T (A) 1
AMSMC-MAR (A) 1
AMSMC-QAC-M (A) 1
AMSMC-QAE (A) 1
Aberdeen Proving Ground, MD 21010-5423

Commander
US Army Technical Escort Unit
ATTN: SMCTE-AD 1
Aberdeen Proving Ground, MD 21010-5423

Commander
US Army Medical Research Institute
of Chemical Defense
ATTN: SGRD-UV-L 1
Aberdeen Proving Ground, MD 21010-5425

Commander
US Army Medical Bioengineering Research
and Development Laboratory
ATTN: SGRB-UBG (Mr. Eaton) 1
SGRB-UBG-AL, Bldg 568 1
Fort Detrick, Frederick, MD 21701-5010

Director
US Army Research Office
ATTN: AMXRO-CB (Dr. R. Ghirardelli) 1
AMXRO-GS 1
PO Box 12211
Research Triangle Park, NC 27709-2211

Commander
US Army Cold Regions Research and
Engineering Laboratory
ATTN: CRREL-RG (Mr. G. Aitken) 1
Hanover, NH 03755-1290

Commander
US Army Armament Research and
Development Center
ATTN: SMCAR-LCE-P (Dr. S. Morrow) 1
SMCAR-LCE-C (Dr. H. Matsugama) 1
SMCAR-LCU-CE 1
SMCAR-SCA-E 1
SMCAR-SCA-W (Mr. O. Saucyn) 1
SMCAR-SCF-SD (Mr. Rosenbluth) 1
SMCAR-SCS 1
SMCAR-TSS 2
Dover, NJ 07801-5001

Project Manager
Cannon Artillery Weapons Systems
ATTN: AMCPM-CAWS-A 1
Dover, NJ 07801-5001

Director
Los Alamos National Laboratory
ATTN: T-DOT, MS P371 (S. Gerstl) 1
Los Alamos, NM 87545

Commander/Director
US Army Atmospheric Sciences Laboratory
ATTN: DELAS-AR (Dr. E. H. Holt) 1
DELAS-AS (Dr. C. Bruce) 1
DELAS-AE-E (Dr. D. Snider) 1
DELAS-AE (Dr. F. Niles) 1
DELAS-AR-A (Dr. R. Pinnick) 1
DELAS-AR-A (Dr. M. Heaps) 1
DELAS-EO-MO (Dr. R. Sutherland) 1
White Sands Missile Range, NM 88002-5501

Director
US Army TRADOC Systems Analysis Activity
ATTN: ATOR-TSL 1
ATOR-TDB (L. Dominguez) 1
White Sands Missile Range, NM 88002-5502

Director
Office of Missile Electronic Warfare
ATTN: DELEW-M-TAC (Ms. J. L. Arthur) 1
White Sands Missile Range, NM 88002-5513

Commander
AMC, STITEUR
ATTN: AMXST-STI 1
Box 48
APO New York 09710

Commander
Air Force Aerospace Medical
Research Laboratory
ATTN: TS 1
Wright Patterson AFB, OH 45433-0000

Director
Combat Data Information Center
AFWAL/FIES/CDIC 1
Wright-Patterson AFB, OH 45433-5000

Commander
Foreign Technology Division
ATTN: TQTR 1
Wright-Patterson AFB, OH 45433-6508

Commandant
US Army Field Artillery School
ATTN: ATSF-GA 1
Fort Sill, OK 73503-5600

Commandant
US Army Academy of Health Sciences
ATTN: HSHA-CDH (Dr. R. H. Mosebar) 1
HSHA-IPM 2
Fort Sam Houston, TX 78234-6100

Commander
Aerospace Medical Division
ATTN: AMD/RDSM (Lt Col D. Marshall) 1
AMD/RDTK (Lt Col J. Milligan) 1
Brooks AFB, TX 78235-5000

Commander
US Army Dugway Proving Ground
ATTN: STEDP-SD (Dr. L. Salomon) 1
Dugway, UT 84022-5010

Commander
US Army Dugway Proving Ground
ATTN: STEDP-SD-TA-F (Technical Library) 1
Dugway, UT 84022-6630

Director
US Army Night Vision and Electro-Optics Laboratory
ATTN: DELNV-NV-D (Dr. Buser) 1
DELNV-NV-V (L. Obert) 1
Fort Belvoir, VA 22060-5677

Commander
Marine Corps Development and Education Command
ATTN: Code D091, SPWT Section 1
Quantico, VA 22134-5080

Commander
US Army Nuclear and Chemical Agency
ATTN: MONA-CM 1
7500 Backlick Road, Bldg 2073
Springfield, VA 22150-3198

Administrator
Defense Technical Information Center
ATTN: DTIC-DDAC 2
Cameron Station, Building 5
Alexandria, VA 22304-6145

Director
Institute for Defense Analysis
ATTN: Mr. C. H. Leatherbury 1
1801 N. Beauregard Street
Alexandria, VA 22311

Commander
US Army Materiel Command
ATTN: AMCCN (BG Robinson) 1
AMCMT-M 1
AMCSF-C 1
5001 Eisenhower Avenue
Alexandria, VA 22333-0001

Commander
Naval Surface Weapons Center
ATTN: Code E4311 1
Code F56 (Mr. D. Marker) 1
Dahlgren, VA 22448

Commander
US Army Foreign Science and Technology Center
ATTN: AMXST-CW-2 (F. Poleski) 1
220 Seventh Street, NE
Charlottesville, VA 22901-5396

Director
Applied Technology Laboratories
ATTN: SAVDL-ATL-ASV 1
SAVDL-ATL-ASW 1
Fort Eustis, VA 23604-5577

Commander
US Army Training and Doctrine Command
ATTN: ATCD-N 1
Fort Monroe, VA 23651-5000

Commander
Tactical Air Command
ATTN: DRP 1
Langley AFB, VA 23665

Commander
US Army Logistics Center
ATTN: ATCL-MG 1
Fort Lee, VA 23801

Commander
HQ, 5th Infantry Division
ATTN: Div Cml Off 1
Fort Polk, VA 71459

McDonnell Douglas Astro Company
ATTN: Mr. J. Adams (A-3-210,11-1) 1
5301 Bolsa Avenue
Huntington Beach, CA 92647

Toxicology Information Center, JH 652
National Research Council 1
2101 Constitution Avenue, NW
Washington, DC 20418

Creative Optics 1
25 Washington Street
Bedford, MA 01730

Science Applications Inc.
ATTN: Dr. F. G. Gebhardt 1
3 Preston Court
Bedford, MA 01730

Battelle, Columbus Laboratories
ATTN: TACTEC 1
505 King Avenue
Columbus, OH 43201

Science Applications Inc.
ATTN: Mr. R. E. Turner 1
1010 Woodman Drive, Suite 200
Dayton, OH 45432

END

FILMED

3-85

DTIC